Identification of Reactive Power Reserve in Transmission Network

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Abstract— **The paper describes importance of the reactive power control basing on the failures and control problems in the Polish transmission networks. A detailed description of the operational difficulties is provided. The paper also presents a highly automated method identifying voltage control areas (VCA), areas prone to voltage instability, and reactive power reserves requirement ensuring voltage stability under all considered contingencies. During the completion of the VCA project testing of the VCA software was limited to power flow models of the Polish Power Grid Operator (PSE) System. A detailed description of the operational difficulties is provided. Conclusions, repairs and prevention undertaking are also described.**

***Index Terms*—Power System Stability, Voltage Security Assessment, Voltage Stability, Intelligent Systems.**

I. Introduction

The quality of the electrical energy supply can be evaluated basing on a number of parameters. However, the most important will be always the presence of electrical energy and the number and duration of interrupts. If there is no voltage in the socket nobody will care about harmonics, sags or surges. A long term, wide-spread interrupt - a blackout leads usually to catastrophic losses. It is difficult to imagine that in all the country there is no electrical supply. In reality such things have already happened a number of times. One of the reason leading to a blackout is reactive power that went out of the control. When consumption of electrical energy is high, the demand on inductive reactive power increases usually at the same proportion. In this moment, the transmission lines (that are well loaded) introduce an extra inductive reactive power.

The local sources of capacitive reactive power become insufficient. It is necessary to deliver more of the reactive power from generators in power plants. It might happen that they are already fully loaded and the reactive power will have to be delivered from more distant places or from abroad. Transmission of reactive power will load more the lines, which in tern will introduce more reactive power. The voltage on customer side will decrease further. Local control of voltage by means of autotransformers will lead to increase of current (to get the same power) and this in tern will increase voltage drops in lines. In one moment this process can go like avalanche reducing voltage to zero. In mean time most of the generators in power plants will switch off due to unacceptably low voltage what of course will deteriorate the situation. In continental Europe most of the power plant are based on heat and steam turbines. If a generation unit in such power plant is stopped and cool down it requires time and electrical energy to start operation again. If the other power plants are also off - the blackout is permanent [1].

II. An Operational Difficulties In Transmission Networks Arose From Reactive Power

The difficulties showed up on June 26, 2006. The prediction for power consumption on this day was 18200 MW (in the morning peak) what was much higher compared with June in last year or previous years. This power was planed to be supplied from 75 generation units. Above these, there were a hot power reserve of 1350 MW (in this 237 MW second-reserve, 656 MW minute-reserve) and a cold reserve of about 2600 MW. In the north-east Poland there is not any grid-generation. The closest to this region is Ostroleka Power Plant, which in that time from three 200 MW units has two in operation and one set off for maintenance. In early morning of the 26th one unit in Power Plant Patnow had to be switched off and before noon four other units (two in Kozienice P. P. and two in Laziska P. P.) were switched off as well. All these unites were the main supplier to the north-east region of Poland. At 7 o'clock 570 MW of power was lost. At the same time the consumption prediction appeared to be wrong - the consumption was 600 MW higher and there was also much higher demand on reactive power. At 13 o'clock there was an unbalance of 1100 MW. In mean time one unit (in Dolna Odra P. P.) had been activated. However further activation from cold-reserve required more time (about 6 hours) because of technological reasons. Unusual heat wave spreading throughout the country caused deterioration of the operational conditions in power plants. Due to lack of sufficient amount of cooling water and exceeded water temperature levels the generating capacities of some power plants systematically decreased. That situation concerned mainly the power plants located in the central and northern part of Poland, the loadings of some transmission lines reached the acceptable limits what in turn cause the necessity of generation decrease in power plants located outside the mentioned region. The control of reactive power became critical. About noon the voltages were low, but still within limits. Rising demand and lack of additional reactive power sources brought further voltage decrease.

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The transformer voltage control had as a priority to keep constant the voltages in 110 kV networks. At 13 hours, most voltages in central and north Poland were below the limits. The generation units in Ostroleka P. P. worked with full power providing also about 100 MVA of reactive power each. They worked with automatic control of reactive power generation. Further increase on reactive power demand caused power oscillation between these two units, and as a consequence switching off one of them (due to large current) at 13:04. The voltage went down and in four minutes the second unit was also off because the voltage was too low. Lost of 400 MW and 200 MVA reactive in critical region affect dramatically all the system. The voltage became much below acceptable limits. All small, local power stations and heat-combine power stations were off immediately. A big unit in Kozienice P. P. was off at 13:08. A DC link to Sweden, that supplied the region with 300 MW was off, as well as its huge battery of capacitors. To rescue the power grid additional power from neighbouring countries has been bought: 400 MW from Czech Rep., 100 MW from Slovak Rep. and 500 MW from Germany. In this time a sharp reduction of consumption was introduced. Switching off about 100 MW loads and a few lines allowed to stabilized the voltages in north of Poland and to put back in operation the units in Ostroleka and Kozienice P. P. About 16 hours the system operation returned to normal conditions.

III. A Reactive Power Management In Transmission Networks

The crises situation described above shows a development of blackout without any unusual events like explosion, storm, hurricane, etc. The existing generation was sufficient to cover all the demand. The transmission capacity was much higher than necessary. The power grid is equip with automatic reactive power and voltage control system. This system also worked correctly. Despite the above a serious problem appeared. The reactive power compensation is a service that is location dependent. Transmission of reactive power over long distances is not only not economical but also ineffective from control point of view. Reactive power flow involves generation of additional reactive power. In normal operating conditions the control system manage to adjust generation of reactive power in power plants and to control the voltages. If the location of reactive power sources is inadequate, the control system may lead the power grid to a blackout [2].

Since it is well understood that voltage security is driven by the balance of reactive power in a system, it is of particular interest to find out what areas in a system may suffer from reactive power deficiencies under some conditions. If those areas prone to voltage security problems, often called critical Voltage Control Areas (VCA), can be identified, then the reactive power reserve requirements for them can also be established to ensure system secure operation under all conditions [3]. To identify VCAs in a given power system, the considered system is stressed to its stability limit for various system conditions under all credible contingencies. At the point of instability (nose of the PV curve) modal analysis is performed to determine the critical mode of voltage instability for which a set of bus participation factors (PF) corresponding to the zero eigenvalue (bifurcation point) is calculated. Based on these PFs, sets of buses and generators that form the various VCAs in a given power system are identified. The identification procedure applies heuristic rules to (a) group contingencies that are related to the same VCA; and (b) identifies the specific buses and generators that form each VCA as described below. The identification program processes the sets of buses and generators corresponding to the PFs obtained from the modal analysis for each system condition and contingency case. Contingencies are clustered if their sets of bus PFs are *similar*. Finally, the program identifies the sets of buses and generators that are common to all contingencies of each cluster. Those sets of buses and generators form the VCAs of the power system.

The VSAT program is used to simulate the scenarios and to compute PV curves for all transfers and contingencies. The objective is to stress the system in the manner specified by the given transfer and to perform modal analysis at the nose point of the PV curve. Modal analysis outputs include the critical mode eigenvalue (zero at the PV nose point), critical mode bus participation factors, and generators that are at their reactive power limit. All generated output files are collected for post-processing in order to generate the database (DB) records for the VCA identification engine. Each VCA identified is related to a cluster of contingencies; these cases are said to "support" that VCA. First, similar contingency cases are clustered and then second, the specific buses and generators that form the VCAs are identified. Before clustering contingency cases, however, a preliminary selection of buses and generators is done at an earlier stage of the VCA identification process as shown in Figure 1.The VCA identification process consists of the following steps [3]:

1) *Selection of Buses for VCA Identification – From modal* analysis results for each contingency, a subset of buses with high PF is selected for further analysis (SFAs): remaining buses are discarded. Several strategies to select such subset can be applied. Generator terminal buses appear in the PF only if the generator exhausts its reactive power reserves (marked as a Q-limited, QL bus).

2) *Clustering of Contingency Cases based on SFAs* – the identification program clusters contingency cases based on similarities. These clusters will be used to identify the VCAs in the power system, as described in Steps 6 and 7 below

3) *Normalization of Generator Buses PFs* - the generator buses PFs are normalized.

4) *Selection of Generators in Cluster Ck* - For each cluster C_k, the frequency of generator bus participations in this Ck is calculated. The generator buses with the highest frequencies are selected to represent the cluster Ck reactive power reserves and are denoted as GENk.

5) *Clustering of Ck based on GENs* - In this step, a number of Ck are grouped together if their corresponding GEN sets are

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similar. Two GENs are considered similar if certain percentage of generator buses are matched. If GENi (from Ci) and GENj (from Cj) are similar, then Ci and Cj are grouped together into a preliminary VCAm. This VCAm is associated with a set of generator buses GENm that consists of the generator buses of the combined GENi and GENj. The first step in clustering Ck is to select the base set GENx to which other GEN's are compared.

6) VCA identification part A: Selection of buses – For each preliminary VCAm, compute the frequency of each bus. Then select the buses with a frequency greater than a user defined threshold value.

7) VCA identification part B: Selection of generators - For each GENm, get the frequency of each generator bus. Then select the generator buses with a frequency greater than a user defined threshold value The generators associated with these generator buses are the ones that form controlling generators associated with VCAm

A. Heuristic Rules for Base Selection and Similarity Measurement

Selection of a base for clustering process - From the VCA identification process presented in the previous section we can observe that clustering is carried out twice: Clustering contingency cases as described in Step 2 and Clustering Ck based on GENs as described in Step 5. *Measure of similarity between buses/generators sets* – The number of common elements C is counted and compared with a similarity of a user defined threshold *T*. If the number of common elements C is greater than the threshold *T*, then

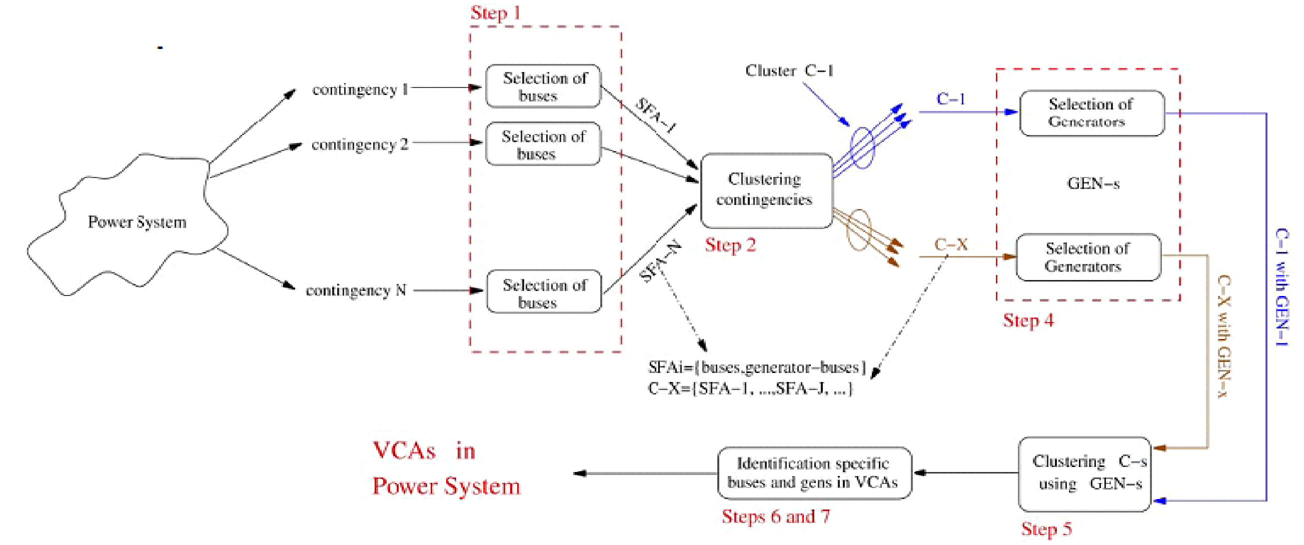

Figure 1. VCA Identification Process

set-*i* and the base set are considered being similar. The similarity threshold *T* is set as a percentage of the number of elements in the largest set (set-*i* or the base set).

B. Reactive Power Reserve Requirements

After the VCAs have been identified, it is desirable to know what reactive power reserves are necessary to maintain in the system in order to ensure voltage stability under all conditions. In the section above describing VCA determination, the generators that control each VCA were identified. It is for these generators that reactive reserve requirement must be established for each VCA. For each scenario analyzed, the pre-contingency reactive output on each controlling generator is recorded at a "secure point" back from the nose of the PV curves. The "distance back from the nose" corresponding to Point "Post Contingency stability limit" is determined based on the required security margin criteria (such as 5% of the transfer load or generation).

IV Summary

An overview of the state-of-the-art of on-line VSA has been presented and a highly automated method for the identification of voltage control areas is described. Voltage control areas describe the regions in a power system that under specific conditions are prone to voltage instability. Intelligent systems hold promise to improve VSA speed, provide adaptive learning capabilities and offer the ability to identify key system parameters. An example of an intelligent system framework using decision trees has been described. Work in this area is continuing toward a pilot implementation at a PSE Operator host site.

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